INF 2178 Technical Assignment 4

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Hypothesis

Null Hypothesis (H0): There is no significant interaction effect between time (visit number or MR Delay) and group (Demented vs. Nondemented) on cognitive decline measured by the Mini-Mental State Examination (MMSE) scores. This suggests that the rate of cognitive decline over time is similar between the Demented and Nondemented groups.

Alternative Hypothesis (H1): There is a significant interaction effect between time and group on MMSE scores, indicating that the Demented group experiences a different rate of cognitive decline over time compared to the Nondemented group.

Exploratory Data Analysis

The box plot shows the distribution of Mini-Mental State Examination (MMSE) scores over two visits, segmented into three groups: Nondemented, Demented, and Converted. MMSE scores are used to assess cognitive impairment, with higher scores indicating better cognitive function.

From the first to the second visit, the Nondemented group shows a slight decrease in mean MMSE score. In contrast, the Demented group shows a more pronounced decrease, suggesting a possible progression of cognitive decline. The 'Converted' group - who were likely initially 'Nondemented' but later changed status - have a median score that falls between the 'Nondemented' and 'Demented' groups at both visits, which may indicate an intermediate stage of cognitive change.

In the 'Demented' group, a wider interquartile range (IQR) is observed at the first visit compared to the second visit, suggesting a greater initial variability in the level of cognitive impairment. Conversely, the Nondemented and Converted groups maintain a relatively consistent IQR across visits.

Outliers are noted in the 'Nondemented' group for both visits and in the 'Demented' group for the first visit, indicating individuals with significantly lower MMSE scores than their peers. The persistence of outliers in the non-demented group may warrant further investigation into possible early signs of cognitive decline.

Two-way Mixed ANOVA

The results of the two-way mixed ANOVA indicate significant effects of both group membership and visit number on MMSE scores, as well as a significant interaction between these two factors.

Group Effect (Between-Subjects Factor): $F(2, 140) = 56.21233$, $p < .001$ ($p = 1.201604e-18$).
This result is highly significant, indicating strong evidence that the mean MMSE scores differ between the groups (Nondemented, Demented, Converted). The effect size, measured by partial eta squared ($np^2 = 0.445379$), suggests a large effect according to conventional benchmarks.

Visit Effect (Within-Subjects Factor): $F(1, 140) = 8.859368$, $p = .003$ ($p = 3.436529e-03$).
The significance of the visit number indicates that MMSE scores change from Visit 1 to Visit 2, regardless of group membership. The effect size is smaller ($np^2 = 0.059515$), which suggests a moderate effect.

Group x Visit Interaction: $F(2, 140) = 3.365255$, $p = .037$ ($p = 3.737081e-02$).
The interaction is also significant, suggesting that the change in MMSE scores from Visit 1 to Visit 2 is not consistent across groups; the effect of the visit on MMSE scores depends on the group membership. The effect size for the interaction is small ($np^2 = 0.045870$).

The 'eps' column typically relates to the epsilon adjustment for the sphericity assumption, but here it's shown as NaN for the Group and Interaction and as 1.0 for Visit, suggesting that sphericity may not be applicable for these particular within-subjects comparisons, likely due to having only two levels.

Post_hoc Tests

Post hoc tests following the two-way mixed ANOVA reveal significant differences in cognitive performance as measured by MMSE scores between subject groups and visits. First, there is a significant decline in scores between Visit 1 and Visit 2, highlighting the progressive nature of cognitive change. The Converted group shows a distinct pattern; their scores are significantly different from both the Nondemented ($p < 0.001$) and Demented ($p < 0.001$) groups, with a moderate to large effect size, suggesting a transitional cognitive state between the other two groups.

Most notably, there is a profound and highly significant difference in MMSE scores between the 'Demented' and 'Nondemented' groups ($p < 0.001$), with a large negative effect size indicating worse cognitive performance in the 'Demented' group. Furthermore, the interaction effects are significant for all group comparisons across visits ($p < 0.05$), indicating that the trajectory of cognitive decline is not consistent across groups. These interactions suggest that the cognitive decline of the Demented group is more pronounced over time than that of the Nondemented and Converted groups. The Bayes factor supports these findings, providing strong evidence against the null hypothesis. This detailed analysis highlights the heterogeneity of cognitive decline across dementia status.

Regression test model 1: Without interaction

The regression output for Model 1, without interaction between the Visit and the Group, shows that both group membership and visit number significantly predict MMSE scores. The coefficient for the group indicates that compared to the baseline (Group 0), Group 1's MMSE scores are significantly lower by 3.9 points ($p < 0.001$), reflecting greater cognitive impairment. Visit number also has a significant effect, with MMSE scores decreasing by 0.582 points with each visit ($p = 0.002$), consistent with cognitive decline over time.

Regression test model 2: With interaction

Model 2 includes the interaction between the Visit and the Group. Here, the coefficient for the Group 1 is still negative and significant ($p < 0.001$), suggesting that this group has lower MMSE scores than the baseline by 4.363 points. However, the interaction term between Visit and Group 1 is not significant ($p = 0.634$), suggesting that the rate of decline over visits does not significantly differ between Group 0 and Group 1. In contrast, the interaction term between Visit and Group 2 approaches significance ($p = 0.067$), indicating there might be a different pattern of cognitive decline for Group 2 compared to the baseline, but this result is not robust at a conventional alpha level of 0.05.

Interaction plot

The interaction plot for MMSE scores over visits by group shows that cognitive performance as measured by the MMSE varies between groups and over time, although the differences between visits within each group appear to be minimal. The graph shows three lines representing each group (0, 1, and 2), with the MMSE score on the y-axis and the number of visits on the x-axis.

Group 0's line is relatively flat, indicating stable MMSE scores between Visit 1 and Visit 2, with consistently high scores indicating less cognitive impairment. Group 1, which has significantly lower MMSE scores, also shows a relatively flat line, indicating that their cognitive performance is lower

but does not significantly decline between visits. Group 2 shows a slight decline, as indicated by the downward slope of the line, suggesting some cognitive decline over time.

The scatter points for each group represent individual observations, and the plot shows some variability within the groups, particularly in Group 1, which has a spread of scores that extends to the lower end of the scale. However, the absence of a steep slope in any group suggests that any changes in MMSE scores from Visit 1 to Visit 2 are relatively subtle and not characterized by dramatic declines within this time frame.

Assumption checks

- Sphericity: the test returns a value of 1.0, which indicates that sphericity is assumed to be met perfectly.
- Normality test of model 1 and model 2: both indicate that the assumption of normality is not met. The test statistic W is close to 1 for both models, which under different circumstances might suggest that the data is normally distributed. However, the p-values for both tests are very low (2.337238e-09 and 5.787738e-09 respectively), which is well below the typical alpha level of 0.05. This leads to the rejection of the null hypothesis that the data is normally distributed.
- Normality of Two-way Mixed ANOVA(histogram and Q-Q plot):
    - Histogram of Residuals: This plot shows the frequency distribution of the residuals from your mixed model. If the residuals are normally distributed, the histogram should resemble a bell curve. The symmetry and shape of the distribution give an initial impression of normality. While the histogram you provided suggests a roughly bell-shaped curve, indicating potential normality, the presence of skewness or outliers can suggest deviations from the assumption.
    - Q-Q Plot: This plot compares the actual residuals to a perfectly normal distribution by plotting their quantiles against the theoretical quantiles of a normal distribution. Points that fall approximately along the reference line indicate that the residuals have a distribution that is close to normal. In the provided Q-Q plot, the general trend follows the line, but deviations, especially in the tails (the ends of the distribution), indicate that the residuals may have heavier tails than a normal distribution, suggesting some departure from normality.

Statistical power analysis

The graph visualizes a power analysis for t-tests with an effect size of 0.7, a significance level (alpha) of 0.05, and a desired power of 0.91. The power curve illustrates how the power of a t-test increases as the sample size increases.

From the graph, we can see that the power of the test (the probability of correctly rejecting the null hypothesis when it is false) increases as the sample size increases. The blue line represents the power curve, and the red dashed line indicates the desired power level of 0.91. The green dashed line shows the required sample size of approximately 45.45 subjects per group to achieve this power with the specified effect size and alpha level.

Interpreting the graph, we see that if the sample size is less than 45.45, the power is less than the desired 0.91. When the sample size reaches approximately 45.45, the power meets the desired threshold, indicating that this is the minimum sample size required to detect an effect size of 0.7 with a high probability while maintaining a 5% probability of a Type I error.

For practical purposes, since we cannot have a fraction of a participant, you would round up to the nearest whole number, which means you would need at least 46 participants per group to achieve the desired statistical power.

Further analysis

Several additional analyses may be informative to further explore research questions related to the trajectory of cognitive decline. First, a more nuanced view of how MMSE scores change over time within individuals would be provided by examining individual trajectories of cognitive decline through longitudinal data analysis. This can be done by taking into account individual variability in cognitive trajectories, using growth curve modeling or time series analysis.

Next, subgroup analyses may reveal important differences, such as whether certain demographic factors, such as age, education, or socioeconomic status, interact with dementia status to influence rates of cognitive decline. This would require stratifying the data. Alternatively, these variables could be included as covariates in a model.

Finally, to complement the quantitative findings, qualitative data, such as clinical notes or patient interviews, could provide context to the numerical trends and help identify potential unmeasured factors that influence cognitive decline. For a holistic understanding of the data and the real-world implications for patients with dementia, these mixed-method findings could be invaluable.